

A REVIEW OF LITERATURE ON THE ENVIRONMENTAL IMPACT OF DE-ICING COMPOUNDS AND SNOW DISPOSAL

1974



Ministry
of the
Environment

The Honourable
William G. Newman,
Minister

Everett Biggs,
Deputy Minister

Copyright Provisions and Restrictions on Copying:

This Ontario Ministry of the Environment work is protected by Crown copyright (unless otherwise indicated), which is held by the Queen's Printer for Ontario. It may be reproduced for non-commercial purposes if credit is given and Crown copyright is acknowledged.

It may not be reproduced, in all or in part, for any commercial purpose except under a licence from the Queen's Printer for Ontario.

For information on reproducing Government of Ontario works, please contact ServiceOntario Publications at copyright@ontario.ca

A REVIEW OF LITERATURE ON THE ENVIRONMENTAL IMPACT
OF DEICING COMPOUNDS AND SNOW DISPOSAL
FROM STREETS AND HIGHWAYS

A REPORT TO THE
TECHNICAL TASK FORCE ON
SNOW DISPOSAL

Water Resources Branch
Ontario Ministry of the Environment
May, 1974

MOE
REV
ABPV

- C O N T E N T S -

ABSTRACT

INTRODUCTION

1. MAIN OPERATIONS FOR SNOW AND ICE REMOVAL

- 1.1 Plowing and Blowing of Snow
- 1.2 Hauling and Dumping of Snow
- 1.3 Thermal Melting of Snow
- 1.4 Chemical Melting of Snow
- 1.5 Spreading of Abrasives

2. ENVIRONMENTAL EFFECTS OF SNOW REMOVAL

- 2.1 Highway and Street De-Icing
 - 2.1.1 The Corrosion of Auto-body Steel and Highway Structure
 - 2.1.2 The Contamination of the Surface and Subsurface Waters and Consequent Effects on Biota
 - 2.1.3 The Contamination of Soil and Injury to Roadside Vegetation
- 2.2 Snow Disposal

3. POLICIES AND PROGRAMS ASSOCIATED WITH MINIMIZING THE DELETERIOUS EFFECTS OF SNOW DISPOSAL

4. ADDITIONAL STUDIES RECOMMENDED IN THE LITERATURE

REFERENCES

List of Reviewed Literature and Environmental Authorities Consulted

ABSTRACT

This report was prepared by the Water Quality Branch of the Ontario Ministry of the Environment and reviews the available information on the environmental effects resulting from road de-icing and snow disposal. A brief review of the methods, equipment and materials used for snow and ice removal is also included. The literature generally concludes that highway de-icing and direct disposal of snow can cause environmental hazards, however, authors tend to agree that research is required to assess the degree of adverse effects of these practices.

It appears that the design of most snow removal equipment has changed little since the time of early development of this equipment and that limited engineering information on snow removal equipment is available. Additional studies, recommended in the literature and required to assess and reduce the environmental impact of snow disposal and ice removal from roads, are also included in this report.

INTRODUCTION

During the past twenty years, significant growth in motor vehicle density and use, coupled with an increasing number of miles of highways, has intensified the demand for the removal of snow and ice from surfaces of roads. At the same time, this increase in traffic volume has contributed to higher concentrations of contaminants in the roadside windrows of snow awaiting removal.

Snow removal technology in cities developed rapidly following the appearance of the automobile in the years shortly after the turn of the twentieth century. There have been no dramatic changes in the design of most snow removal equipment since the time of its early development. However, the many minor modifications made over the years have collectively contributed to a vast improvement in the efficiency of such units. This increased efficiency allows municipal jurisdictions to remove the snow in a much shorter time period than was previously possible. By so doing, the snow and ice does not have as many added pollutants as it would if allowed to remain for an excessive period of time prior to its removal.

The original key to snow disposal plans in many cities was to be the use of sewers for flushing away snow. At a snow removal conference in 1914 in Philadelphia, one of the earliest on record, it was reported that salt was extensively used for snow removal in England and France. The conference doubted that this practice would be successful in North America

because of the heavier snowfalls, and also because of anticipated objections by the Society for Prevention of Cruelty to Animals *(Minsk, 1970).

In the 1930's, the construction of bigger and heavier blade plows and rotary plows provided major advances in winter highway maintenance (Bain, 1970). Prior to 1941, it was the usual practice to spread chloride-treated sand on snow or ice covered pavements. More recently, there has been a tendency to decrease the use of sand and increase the use of salt as a de-icing compound.

Growing concern has developed over pollution arising from both the runoff from de-icing chemicals applied to streets and highways and the direct disposal to watercourses of snow removed from these roads. Consequently, an environmentally oriented survey of the literature on road de-icing and snow disposal was undertaken to assess the adverse effects of these practices.

This report is a summary of findings of a literature review. It was realized at the beginning of this study that the review of available literature would not furnish all the answers for the formulation of a snow disposal policy, but it would clarify the knowledge of the effects of snow removal, and, hopefully, would stimulate further work in this field.

* It was anticipated that the SPCA would argue that salt would cause injury to horses hooves etc.

1. MAIN OPERATIONS FOR SNOW AND ICE REMOVAL

- Plowing and Blowing
- Hauling and Dumping
- Thermal Melting
- Chemical Melting
- Spreading of Abrasives

Some experimentation is being conducted with sonic and electronic systems, however, these will not be readily available in the near future.

1.1 PLOWING AND BLOWING OF SNOW

A century ago, the plowing of snow was the most popular form of snow removal in cities located in northern areas. Recently, 'plowing type' snow removal operations have been categorized by E.C. Bain (1970) who suggested the following classification of snow removal equipment:

<u>Class</u>	<u>Definition</u>	<u>Type of Operation</u>
1	Snow-doing	Very slow plowing
2	Snow-plowing	Plowing at 15-20 m.p.h.
3	Snow-throwing	Plowing at greater than 20 m.p.h.
4	Snow-blowing	Rotary plowing

The speed of the snow removing equipment is the criterion of this suggested classification. At slow speeds, snow is pushed or plowed, but at the faster

speeds of 20 to 30 m.p.h., it is thrown. Snow-throwing equipment generally involves high powered vehicles capable of throwing large tonnages of snow (e.g. railroad and expressway maintenance).

1.2 HAULING AND DUMPING OF SNOW

Snow disposal on land sites, frozen lakes and rivers has been commonly used by municipalities as a convenient and economic means of snow disposal, especially the dumping of snow to lakes and rivers. Such dumping of snow concentrates pollutants present in snow (toxic metals, oil, nutrients, organics and solids) that may otherwise not gain access (solids) to the watercourse or may have gained access over a greater distance and time, thereby reducing their harmful effects.

1.3 THERMAL MELTING OF SNOW

In situ, thermal melting can be divided into two categories (Lockwood, 1965):

- (a) External systems utilizing infra-red energy that can be either electric or gas operated.
- (b) In-slab systems, including imbedded, electrically-heated cables or pipes containing heated fluids or steam.

Thermal melting is generally more expensive than other methods and therefore, used to a limited extent (toll stations, ramps, busy intersections, etc.).

Snow melters can be used for melting snow cleaned from streets and parking areas. These machines involve three elements: a heat source, a melting chamber and a discharge system. Mobile melters most frequently discharge into storm drains and are generally used for melting relatively small quantities of snow. Stationary melters are utilized for melting large quantities of snow especially in areas with extremely cold winters.

1.4 CHEMICAL MELTING OF SNOW

A number of chemicals are used for snow and ice melting. The basic requirement is that the substance be soluble in water and lower its freezing point. Some chemicals have an additional advantage for de-icing by giving off heat as they go into solution (e.g. calcium chloride). Chemical de-icing includes chemicals such as urea and sodium chloride. Cost is a big factor in the selection of a de-icer. This cost varies with the supplier and geographic location, however, calcium chloride costs approximately three to four times as much as sodium chloride.

The Ontario Ministry of Transportation and Communications has carried out limited studies as to the feasibility of utilizing calcium chloride for road de-icing. The results, as reported, did not indicate that the chemical was desirable to use due to its cost, the fact that it is difficult to handle and that once in solution it had deleterious effects upon some materials, such as leather, rubber, metals, etc. However, the above Ministry retains a limited stock of calcium chloride for occasions when sodium chloride cannot be used (if temperature drops below 0 degrees F).

Urea is another chemical frequently mentioned as an alternative to salt. It is generally considered to be less corrosive than the chlorides but its extensive use is uneconomical and could contribute to the nutrient enrichment of streams. Urea was tested by the National Research Council, Ottawa (1964). Results did not indicate that this chemical warranted being utilized on a wide scale. Urea is not effective in cold winter conditions and must be used in quantities approximately twice as great as sodium chloride. However, urea is widely used by the aviation industry where the non-corrosivity upon aircraft metals plays the most important role in the selection of de-icing chemicals.

The following chemicals have been tried for de-icing purposes (Salt Institute, 1971).

<u>De-Icing Chemical</u>	<u>Eutetic Temperature oF *</u>
Sodium chloride	- 6
Potassium chloride	+13
Ammonium sulfate	- 2
Calcium chloride	-59
Magnesium chloride	-28
Urea	+11
Aluminum chloride	-65

* Eutetic temperature is defined as the lowest melting point of the mixture of two or more substances.

Many variables, such as temperature, air humidity, grain sizes, depth of the snow or ice, and traffic effect the efficiency of the de-icing process. Therefore, the rate of application must be determined empirically. Past experience indicates that de-icing chemicals are effective and economical when the snowfall is light, up to a depth of 2-3 inches (Struzeski, 1969).

The Ontario Ministry of the Environment has contacted major municipalities in Ontario concerning their winter roads maintenance practices. The survey indicated that application rates up to 1,800 lbs. of salt per 2 lane mile of road per treatment are not uncommon. However, most municipalities utilize the salt application rates recommended by the Ontario Ministry of Transportation and Communications (1972), the rates being as follows

- 450 lb/2 lane mile for rural roads (per treatment)
- 800 lb/2 lane mile for urban roads (per treatment)

The large majority of salt is currently applied to road surfaces by vehicles having mechanical spreaders (tail-gate spreaders, hopper-type spreaders, dump trucks with discharge pipes, etc.). Improper calibration and operation of this equipment may lead to the application of salt at excessive rates. The Ontario Ministry of Transportation and Communications' policy is to store large quantities of de-icing chemicals in stock piles which are

covered and placed upon waterproof pads. The salt is stored either in salt sheds or in dome-like structures (beehives). These domes, which represent the most advanced means of storing the de-icing chemicals, are primarily used to store large quantities of salt-sand mixture. These units can store up to 5,000 cubic yards of salt-sand mixture under one roof.

In Northern Ontario, where cold weather conditions dictate the use of sand-salt mixtures, covering of storage piles is, in a few instances, achieved by a plastic coating sprayed on the pile's surface. This technique minimizes the leaching of salt out of this mixture and thus prevents local salt pollution of adjacent land and watercourses.

Authorities responsible for highway and road maintenance generally agree that sodium chloride is readily available, easily handled, economical and highly efficient. Efficiency of deicing salt depends mainly on its surface and hence its particle size. There has been considerable discussion in available literature as to the optimum particle size for de-icing salt. Although it is well agreed that the melting action of fine salt is higher than that of coarser material, the latter is utilized to a greater degree. The coarser salt penetrates relatively more easily into hard ice surface and maintains its activity over a much longer time period than the fine material.

Experiments have shown that dry salt has no direct melting action; melting occurs only after the salt has dissolved and formed a solution by taking moisture

from the air. The resultant solution may be useful in both preventative and maintenance treatments during or immediately after precipitation. A technique utilizing a sodium chloride solution was introduced for de-icing of roads in Italy (Scotts, 1970). This represented a departure from the conventional treatment with solid de-icing chemicals. The author described the technique utilizing a solution of calcium chloride.

However, this method did not prove efficient for treating thick layers of ice. Another experiment with salt solution has been carried out in North Dakota, U.S.A. (Kyser, 1971). Brine solution, a by-product separated from crude oil, was applied directly on roads at a rate of 130 gallons per mile.

Where the ice was thicker (more than three quarters of an inch), dry salt was added behind the brine truck. According to the author, the results of this test were satisfactory. However, application of brine solution is not likely to be used in Ontario. In Southern Ontario, the air is relatively humid and thus the salt applied on the road becomes "active" in a relatively short period of time after applications. Furthermore, the Ontario Ministry of Transportation and Communications anticipates corrosion problems and the need for frequent servicing of equipment spraying a brine solution. These conclusions are supported by experience gained from summer spraying of gravel township and county roads with solutions of calcium chloride to prevent dust problems. The majority of contractors providing this service complain about the rapid corrosion of the spraying equipment.

Dunnery (1970) describes the treatment of ice from roads by the patented liquid called "Union Carbide UCAR De-icing Agent". This fluid is essentially a glycol-water mixture having a BOD_5 in the order of 300,000 mg/l (Schultz, 1973). It is therefore not considered acceptable for road de-icing, but more applicable for controlled situations such as air craft de-icing.

Traffic is considered to be an important parameter in snow removal considerations. The heat generated by the friction of the tires on the pavement and the mechanical splashing of snow are the two primary means of removal associated with traffic. However, until the snow reaches a free water content of 30%, traffic will not effectively melt snow from roadways (Richards and Assoc., 1972). To obtain 30% free water content in snow, it would be necessary to apply 220 pounds of salt per two lane mile of road with one inch of snow at an air temperature of 4 degrees F. According to Richards and Assoc. (1972), the remaining snow will be removed by traffic whenever the traffic density is greater than 50 vehicles per hour.

1.5 SPREADING OF ABRASIVES

Although the use of abrasives has declined, they are still important for winter time highways maintenance. A number of communities use combinations of salt and sand, or grit at the rate of 50-100 lb. of salt per cubic yard of material (Struzeski, 1971). This has three advantages:

- (a) traction is increased immediately.

- (b) amount of salt is reduced.
- (c) sand piles with slight moisture content do not freeze solid or into huge chunks of sand.

The cost saving resulting from the latter might be offset by the cost in clearing tons of grit from pavements. Moreover, the use of abrasives for street maintenance could possibly lead to higher corrosion of automobile bodies due to pitting of the painted surfaces and a subsequent oxygen starvation type of corrosion. (Richards and Associates, 1972)

The average unit cost/lane mile/inch snowfall for total snow and ice control operations for the years 1970-1973 in the City of Ottawa was \$1.79 (J.L. Richards and Assoc., 1972). The costs of operation are influenced by daily climatic conditions. Although the unit cost/lane mile/inch snowfall is a useful yardstick for comparison within the same city, it is less meaningful for the comparison of distant cities with different climates and operating techniques.

2. ENVIRONMENTAL EFFECTS OF SNOW REMOVAL

2.1 HIGHWAY AND STREET DE-ICING

A review of the literature indicates that de-icing chemicals may cause damage across a wide environmental spectrum. Side-effects of highway salting include:

- the corrosion of highway structures and vehicles.
- the contamination of the surface and subsurface water supplies and consequent effects on aquatic biota.
- the contamination of soils, and effects on trees and grasses.

2.1.1 The Corrosion of Auto-body steel and Highway Structures

The literature on steel corrosion concludes that salt without moisture does not cause corrosion. However, when the metal is exposed to salt water, an electrolytic reaction which converts the metal to its oxide form, will likely proceed at a much faster rate compared to water alone. Anon (1957) indicates that chlorides in water are corrosive even to stainless steel.

These facts have been studied by Fromm (1967) who tested the effect of salt upon auto-body steel in many representative areas in Canada by exposing the auto-body steel to:

- atmospheric conditions only.
- de-icing salt.

- salt with corrosion inhibitors.

This study indicates that salts cause an increase in the rate of corrosion directly in proportion with the amount of salt used. The same result was obtained in the U.S.A. by the Ford Motor Co. in Minnesota. In the Toronto area, for example, it was proven that the use of salt doubles the rate of corrosion (Fromm 1967). Fromm also concludes that none of the corrosion inhibitors tested produced a significant reduction in the amount of corrosion.

Laboratory studies have shown that sodium chloride and calcium chloride may have damaging effects on concrete (Struzeski, 1969). Defects caused in bridge structures include large cracks, splitting or shelling out of the surface layer of the deck and surface pitting. However, according to the Portland Cement Association, U.S.A., properly designed concrete surfaces made with top-quality air entrained concrete have little need for further protection against de-icing chemicals commercially used (Panarase, 1971). The exceptions are ice-removal agents containing ammonium nitrate and ammonium sulfate salts. These chemicals could attack any concrete. Experience has shown that de-icing salts may have deleterious effects upon highway structures. The National Research Council in Ottawa (1971), upon the results of laboratory tests and field observations, concluded that salt is the most significant contributor to the deterioration of concrete, but it is not the only factor responsible for concrete failures.

No significant effects that could be attributed to deicing chemicals have been observed for asphalt pavement. According to the Asphalt Institute (1963), no significant deterioration or an appreciable change in the consistency of the asphalt due to de-icing salts was observed while testing a large number of samples under laboratory conditions. Due to the greater amount of heat absorbed by asphalt surfaces, deicing chemicals are considered more effective on these surfaces than on concrete highways at lower temperatures.

2.1.2 The Contamination Of The Surface And Subsurface Waters

And Consequent Effects On Aquatic Biota

The Ontario Ministry of the Environment in its publication "Guidelines and Criteria for Water Quality Management in Ontario" recommends the following chloride concentrations based upon specific water uses.

<u>Type of Use</u>	Desirable Chloride Concentrations (mg/l)	Permissible Chloride Concentrations (mg/l)
Domestic Water Supply	less than 25	250
Agriculture Irrigation	less than 70	150
Tobacco Irrigation	less than 20	70

The requirements for chloride concentration in industrial water supplies varies with the industrial use. The pulp and paper industry, for example prefers low chloride levels of approximately 10mg/l.

Investigations of the potential and actual ground water contamination problems in Ontario are carried out by the Water Quantity Management Branch of the Ontario Ministry of the Environment. Fewer than ten complaints are received annually that relate to salt contaminated wells. These problems are usually associated with uncovered sand-salt storage piles, and less frequently, with

heavily salted road intersections. An investigation into salting at a road intersection in the Ottawa-Carleton area showed that a well 100 feet from the intersection had a chloride concentration of up to 1600 mg/l, while another well 550 feet from the intersection contained up to 900 mg/l of chloride. Other downgradient wells, beyond the influence of the heavy salt dosages at the intersection, were contaminated by normal road salt operations and their water contained up to 360 mg/l of chloride. The background concentration of chloride for this area has been reported as 50 mg/l.

The effects of road salting on ground water quality have not been intensively studied in Ontario, however, problems related to salting of roads have been identified during other investigations. For example, during a gasoline contamination investigation near Woodstock, Ontario, water in wells located in an unconfined aquifer upgradient from a highway were found to contain about 10 mg/l of chloride. On the other hand, water in wells located 100 feet downgradient from the same highway contained an average of 235 mg/l of chloride.

Data gathered from isolated instances, such as those above, suggest that highway road salting does contribute to ground water quality impairment in unconfined or poorly confined aquifers. The paucity of complaints from owners of shallow wells fronting roads indicates that chloride levels in the ground waters probably remain below the taste threshold and/or that users have developed a tolerance to the salt taste of the water.

Valid complaints investigated by the Ontario Ministry of the Environment are brought to the attention of the appropriate municipal or provincial agencies. Sand-salt piles are usually removed to less sensitive areas or are sheltered to prevent salt leaching out of the piles and affected well water supplies are restored. Road salt spreading presents a more complicated problem. As a matter of policy, the Ontario Ministry of Transportation and Communications does not restore supplies affected by salt spreading. In these sensitive areas, the only apparent method of resolving pollution problems is to reduce the rate of salt application to the roads.

Fromm (1971) reviews studies on the buildup of salt in the ground. It appears that salt levels in the ground alongside highways are highest at the surface about five feet from the highways and decrease with distance from the road. At about 100 feet from the highways the levels return to normal. The salt concentration was also shown to be the highest at the surface and almost normal again at a depth of 5 feet. The author does not believe that ground water could be contaminated from road salt to any significant extent.

The report prepared by the Salt Institute (1971) reviewed some recent findings on the environmental effect of salt and came to the conclusion that "Water pollution from de-icing salt is limited to effects on shallow wells near roadways and to small ponds and streams located where they receive direct run-off from roadways. Major waterways do not appear to be con-

taminated".

Hutchinson (1966) analyzed the progression of salt through soil in Maine. The author came to the conclusion that the majority of salt is retained by the soils adjacent to the salted highways, increasing the concentration of salt in soil up to ten times. The investigator does not believe that salt would enter waterways through the soil. Chloride is finding its way into watercourse from many different sources. For example, road salting represents slightly less than 20% of the total chloride input into Lake Ontario (OWRC, 1971). The chloride concentration in Lake Erie increased from 7 mg/l in 1910 to 23 mg/l in 1969. According to the Salt Institute report 1971, about 11% of the increase was due to de-icing salts. Fromm (1971) stressed the fact that although the intensive use of salt started in mid-forties and early fifties, the chloride-time growth curve in the Great Lakes does not reveal any marked increase, but rather a steadily rising chloride curve. It would appear that the increase in chloride levels is largely associated with increasing industrial growth and rising population levels around the Great Lakes. A study on chloride levels in lake Erie by Owenby and Kee (1967) resulted in the following conclusions regarding chloride input into Lake Erie:

- 27% from upstream watershed.
- 4% from municipal wastes.
- 11% from street and highway salting.
- 57% from industry.

Both authors have postulated that if the present trends are maintained, then the chloride levels in 2020 will be 70 mg/l. Dobson (1967) has reported that sodium and chloride levels are changing more rapidly than other chemicals in Lake Ontario. The rate of increase per 10 years was 21% for sodium and 19% for chloride. The author concludes that at this rate of increase, the concentration of sodium and chloride will double in 50 years (to 50 mg/l of Cl), primarily as a result of human activities. Chloride levels in the Lower Great Lakes have shown a three-fold increase since the turn of this century. (Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, International Joint Commission, 1969). A significant portion of the total chloride input to Lake Ontario was attributed to de-icing salts.

Hutchinson (1968) studied the effect of highway salting on the concentration of sodium and chlorides in nine rivers in southwestern Maine. These data showed no consistency in an increase in salt concentration during the winter months. In fact, the sodium levels tended to be highest in September. According to the study carried out by the Ontario Water Resources Commission (1971), streams in the vicinity of Toronto exhibit up to 400% increase in the concentration of chloride in winter.

Judd (1971) stated that salt had an adverse effect on the First Sister Lake, Michigan, because the spring mixing of this lake was prevented by the increased diversity in the lower lake strata which in turn was primarily attributed to contamination by salt. The author claimed that the stratifi-

cation stability of this lake increased in spring so much that even a wind of 50 m.p.h. did not have sufficient force to cause the lake's turnover. However, according to the author, the fall turnover of the studied lake was not affected.

Similar findings have been reported by Bubeck (1971) who observed the increasing salinity from winter runoff accumulating in the bottom of a small bay. The salinity of the dense runoff was sufficient to prevent complete vertical mixing of the bay during the spring due to the increased density gradient imposed by brine solutions.

Kunkle (1972) studied the effect of de-icing upon a small stream in New England. This investigation observed peak chloride concentrations during summer dry periods which he interpreted as indicating that some portion of road salt found its way into soil and finally emerged in the summer ground water input. The author concluded that salt pollution could be restricted to stretches of streams near highways, noting that problems might arise when the stream serves as a public water supply.

A report prepared by The Salt Institute (1971) describes the rapid increase in chloride concentration in a public water supply after the opening of the Massachusetts Turnpike. The same report shows that the chloride concentration usually peaks during the February - May period. For comparison purposes, the following table indicates the chloride content of different waters.

TABLE 2.1.1 Chloride Contents of Various Waters

Type of Water	Chloride Content (mg/l)	Reference
Rain	to 2	Kramer, 1972
Rivers without pollution stress	to 20	Ontario Ministry of the Environment, 1972
Domestic raw sewage	40-150	"
Urine	to 5,000	Hughmanik, 1971
Sea water	to 20,000	Hughmanik, 1971

According to the Highway Research Board (1967), water with 2000 mg/l of chloride has been used for domestic purposes without adverse effects once that the human system adjusted to this water; presently, restrictions on the chloride content of our drinking water are based on taste, rather than health. The same reference, however, stresses the fact that excessive consumption of sodium, another major element from de-icing salt, may be harmful to people with heart or kidney diseases.

Very little is known about the effect of de-icing chemicals on the aquatic biota. Chloride is generally considered to be a non-toxic ion and hence very little data are available as to its effect on the aquatic biota. Hughmanik (1971) reported that fish were killed in farm ponds and small lakes immediately adjacent to highways where salt was used. The same reference reported critical concentrations of sodium chloride affecting biological life as illustrated in Table 2.1.2.

TABLE 2.1.2 Concentrations of Sodium Chloride Affecting Various Biological Life Forms

(Hughmanik, 1971)

Type of Life	Affecting Conc. (mg/l) of NaCl	Type of Effect
Minnows	2,500	Lethal conc.
Daphnia	3,680	Immobilization
Act. sludge	50,000	Digestion retarded

Large quantities of chlorides discharged by industrial plants into the Werra River, Germany, have resulted in fish kills during the winter when the salt content exceeded 12,000 mg/l (Highway Research Board, 1967). The same reference describes the result of one field study where fish disappeared from the stream when chlorides exceeded 1,000 mg/l. The effect of chlorides on gold fish was studied by the Madison Rivers and Lakes Commission (1962) with no effect being noticed during a 24-day period while the concentration of chloride was 1,200 mg/l. A study by Dawton & Eggert (1957) describes the tolerance of slime organisms to sodium chloride in trickling filters. Following a sharp increase in the sodium chloride levels (up to 20,000 mg/l) treatment efficiency was impaired in the filter, but the slime growth recovered in about a day. Little effect on the effluent BOD values was noted with sodium chloride concentrations of up to about 10,000

mg/l, but at a concentration of 50,000 mg/l of chloride the effluent BOD values were about doubled. A similar study was undertaken by Kincannon and Gaundy (1968) in which a biological waste treatment system was tested at various concentrations of sodium chloride in the inflowing synthetic waste. During the period of increasing the salt concentration up to 30,000 mg/l the system could not maintain a high removal efficiency. However, after an acclimation period the system regained its former rate of reaction. The system recovered when the salt concentration was reduced. It was found that steady operation at a salt level of 8,000 mg/l sustained a high reaction rate.

The special additives (such as ferrocyanides) are often mixed with the de-icing salts (serving mostly as anti-caking agents). During the years of 1969-70, the Ontario Ministry of the Environment monitored the levels of cyanide in various streams in the area of Metropolitan Toronto. No significant increase in the concentration of cyanide was observed for the winter seasons.

Burdick (1948) studied the toxicity of ferro- and ferri- cyanide compounds. Ferric ferrocyanide was not harmful to blunt nosed minnows in a concentration of 9,600 mg/l. This compound does not release cyanide upon acidification. On the other hand, sodium ferrocyanide, sometimes added to the de-icing salt, could release cyanide after photo-decomposition, although the author did not find a concentration of 2,000 mg/l sodium ferrocyanide to be toxic to fish.

2.1.3 The Contamination Of Soil and Injury to Roadside Vegetation

Extensive literature, available on salt effects on trees and grasses comprising the roadside environment, concludes that highway salt seriously injures this vegetation.

Linzon (1971) reported that the Phytotoxicology Section of the Air Management Branch of the Ontario Ministry of the Environment has investigated a number of complaints of injury to roadside trees suspected of being injured by salt spray. In these investigations, it has been found that white pine, peach and apple trees are extremely sensitive to salt spray. The symptoms of injury include terminal shoot dieback which is most severe on the row of trees adjacent to the highway with the severity of injury decreasing with distance from the highway. The dieback was accompanied by elevated levels of sodium and chloride in the dead twigs. Trees were rarely injured beyond 150 feet from the road, but this distance was found to vary depending on frequency of salt treatment, highway traffic, height and density of roadside trees, and gradient of the highway.

The report prepared by National Research Council, Ottawa (1971) states that damage to the vegetation occurs mainly at locations where chemicals are applied in large quantity and where traffic splashes the brine on roadside trees. A report by the Highway Research Board (1970) indicates that soil in some areas in proximity to salted highways is becoming polluted by de-icing salts and even "alcali-tolerant" plants could not grow in a soil containing as much as

10,000 mg/l of chloride. Struzeski (1971) reviewed an extensive number of investigations reporting die-offs of plants due to salt contamination. This report indicates chloride accumulations within grasses to be several times lower than the accumulation rate of sodium.

Linzon (1973) reported that salt injures plants by forming intercellular salt crystals which desiccate plant tissues through cell plasmolysis. This form of physiological drought can result in death of the tissue when a threshold level of sodium and/or salt is reached. Toxicity usually occurs when chlorine is in the range of 5,000 to 15,000 ug/g based on the dry weight of tissue.

Davison (1971) gave a summary of adverse effects of excesses of deicing mixtures on the plants along salted highways. They were as follows:

- osmotic stress
- specific toxicity of ions presented in de-icing mixture
- altering the soil pH
- changing the soil permeability

Lacasse (1962) asserts that cumulative applications of highway de-icing salt is responsible for the rapid decline of sugar maples. The same author carried out a similar study in 1964 and came to the same conclusion. Walton (1969) proved a direct correlation between the in-

tensity of highway salting and the death of Norway Maples. According to Struzeski (1971) grasses are not injured by de-icing salts as readily as trees, hence trees are the first in plant biota showing the sign of chloride damage. The same reference indicates that salt sprayed from the passing vehicles can affect trees up to 100 feet from the road. Whittle (1971) does not suggest planting maples along salted highways as this tree exhibits poor salt tolerance. The same reference also indicates that there are other pollutants causing damage to trees (oily deposits from house heating, changes in the water table, ozone, pollution from automobile exhausts, etc.).

Thomas (1967) concluded that excesses of road salt applied on highways may cause the death of Kentucky Bluegrass along the roadside. The author summarized factors governing salt injury to the plants as follows:

- amount of road salt applied
- amount of road salt reaching the vegetation
- water availability
- temperature
- wind velocity
- soil factors
- plant dormancy
- salt tolerance of plants
- cumulative effects

Salt tolerance of grasses and trees has been classified by Richards and Associates (1972), with respect to the capability of the plant, to survive on saline soils. The plants have been categorized as:

- tolerant
- moderately tolerant
- sensitive

Approximately one hundred species are listed in these three categories. Eaton (1971) reports varying degrees of crop injury as a result of accumulation of salt in soil. The author concludes that chloride salts in soil are far more toxic than sulfate salts and that chloride salts inhibit activity of some enzymes.

Results of various studies of the effect of chlorides upon plants and soils are probably hard to apply in the field since the salt once affecting the plant could be "flushed away" while the adverse effect of the salt remains after the salt concentration is significantly lowered.

Increased sodium and chloride concentration was suspected to cause an extensive silver maple decline on the US-7 Highway in Vermont (Highway Research Board, 1970). In this report it was confirmed that the maximum concentration of sodium and chloride may be found at the soil surface at the nearest vicinity of highway. Salt concentration increased during summer and fall. Sodium and chloride ions

entered the soil profile during the winter and penetrated into deeper horizons as time progressed. Higher than normal sodium and chloride concentrations were found to depths of 18 inches and at distances of 75 feet from the pavement. The increase in sodium and chloride content of the soil is manifested through increased uptake of these ions into the leaves and stems of the damaged trees, according to the findings of this report. No damage was observed when the chloride concentration was less than 1,800 mg/l. A chloride concentration of 2,000 mg/l produced leaf scorch, and above 5,000 mg/l produced leaf scorch, defoliation and ultimately death of the tree.

2.2 SNOW DISPOSAL

Investigations of snow dumping into water bodies indicate that such practices can be a significant source of water pollution (Ontario Water Resources Commission, 1971).

In the literature there is little documentation as to the potential hazards of this form of snow disposal. The Ontario Water Resources Commission carried out surveys in which high concentrations of suspended solids, organic material, phosphorus, chlorides, lead and oil were found in the Toronto area snow (Ontario Water Resources Commission, 1971). Average concentrations of pollutants found in snow taken from disposal sites and trucks dumping snow directly to Toronto Harbour are presented in Table 2.2.1.

TABLE 2.2.1 Analysis Of Snow From Disposal Sites In Toronto

<u>Parameter</u>	<u>Concentration (mg/kg)</u>
Total solids	10,500
Chlorides	2,250
Total lead	9.8
Total iron	41.5
Total phosphorus	2
BOD ₅	57

Lead introduced to the snow via automobile exhausts has recently come under review (each gallon of leaded gasoline contains 2.4 to 4.8 grams of tetraethyl or tetra-methyl lead). Analyses of snow disposal sites in Ottawa yielded an average lead concentration of 4.9 mg/l (Richards and Associates, 1972). These results are slightly lower than findings of the Technical Task Force in Toronto, Ontario (see Table 2.2.1) where average concentration of lead in snow was found to be 9.8 mg/kg. The Richards' study (1972) found that lead particles contained in automobile exhaust fumes attach themselves to sand and fine particles. If their findings are true the question would then be whether or not lead remains attached to particulate matter if disposed of in suitable land disposal sites.

Soderlund et al (1970) documents the high level of lead in snowfall in Sweden where lead concentration ranged from 1 to 100 mg/kg with a median concentration of 18 mg/kg. Oil content of the same snow ranged from 2 to 105 mg/kg with a median concentration of 21 mg/kg. Similarly, a high content of lead in snow was found in studies in Columbus, Ohio, where snow contained "about 15 times more lead than the safe limit set for drinking water" (Struzeski, 1971).

Significant quantities of heavy metals (iron, cadmium, chromium, nickel, zinc and copper) were found in snow disposal sites in the Toronto area by Dr. Van Loon from the University of Toronto (1972).

Bandoni (1972) reports high suspended solids concentration in snow being dumped to the Grand River by the City of Galt. Suspended solids in this area ranged from 399 to 2322 mg/kg.

The environmental impact of many pollutants in snow (especially heavy metals) deserves further investigation. Very little is known as to the bio-availability of these contaminants to the plants and organisms affected. The fate of these metals after a number of years on the bottom of rivers or on the soil is still an unanswered question.

Bioassay tests were performed on meltwater from three snow disposal sites in Ottawa by Richards and Associates (1972). No signs of acute toxicity were evident using fingerling rainbow trout on the basis of 96-hour tests. Recent studies including a number of investigations undertaken by Dr. Kramer of McMaster University indicate that the results of bioassays performed on meltwater should be used cautiously when predicting the impact of melted snow upon aquatic biota. It is hypothesized that heavy metals in snow could appear in chelated form rather than as free ions, thereby significantly changing their toxicity. Chelating mechanisms as well as surface active phenomena could possibly explain the high solubilities of heavy metals in snow and rain. Experience has shown that these concentrations exceed the solubility limits of salts of heavy metals.

3. POLICIES AND PROGRAMS ASSOCIATED WITH MINIMIZING THE DELETERIOUS EFFECTS OF SNOW DISPOSAL

In the spring of 1972, the Ontario Ministry of the Environment directed that a Technical Task Force on Snow disposal be formed to develop a policy on roadway de-icing and snow disposal for the province. This Task Force which first met in July, 1972, is composed of members from the Federal Department of the Environment, the Ontario Ministry of the Environment, the Ontario Ministry of Transportation and Communications and several municipal engineers from cities and towns in Ontario. Under the direction of this Task Force, a number of programs have been established to obtain basic data for the development of winter road maintenance policy and to provide guidance for snow disposal practices. Intensive sampling of snow scraped from roadways in Ontario was initiated during the winter of 1972-73, and a wide variety of chemical and physical parameters are being measured. Completion of this project will provide a better insight into the concentration of pollutants in snow from different types of roadways as well as from snow that has been on the ground for both short and long periods of time. This Task Force also co-ordinates the water quality impact study of the direct snow disposal in the Ottawa-Hull area (in co-operation with the National Capital Commission and a consortium of consulting engineers).

The Ontario Ministry of the Environment has contacted several agencies responsible for environmental protection in North America. It appears that very little has been done in the development of regulations concerning the use of road salt on highways, or in formulating a snow disposal policy. Legislation against the use of salt on high-

ways has been passed in Minnesota and has been proposed in Massachusetts, Oklahoma and Vermont (Salt Institute, 1971). No comprehensive policy has been accepted in the State of New York and Ohio concerning the snow disposal and de-icing of roads. In Michigan the Highway Department uses only calibrated spreader equipment for de-icing of roads and has a route priority system whereby certain roads are maintained in a bare pavement condition, utilizing the de-icing procedures as opposed to roadways with lower priorities where only snow removal is employed. In the State of Vermont the "reasonable and proper procedure for highway salting" is enforced by an order issued by the local Department of Water Resources. The order is renewable annually upon application by the local Department of Highways. The order requires:

- (a) following the agreed standards for the application of winter salt on highways;
- (b) reporting every application of de-icing salt in excess of 800 pounds per mile to the local environmental authority;
- (c) covering all salt storage areas;
- (d) conducting investigations of winter road operations by the local Department of Highways particularly as to the minimizing of the discharge of salt to waters.

Snow disposal activities in the U.S. are handled largely at the local and State levels.

Whittle (1971) describes a ban on using salt for de-icing streets in Burlington, Massachusetts. The chloride content of Burlington's wells has risen steadily (up to 272 mg/l) even though the municipality applied relatively minor quantities of salt to the streets.

Mammel (1970) contacted thirteen major cities in North America to determine their policy on the use of salt. Every city contacted proposed to continue using salt as de-icing chemical despite the fact that salt may be detrimental to the environment. In general, most of the cities contacted feel that there is no practical substitute for salt.

Bandoni (1972) in his report concludes that the former City of Galt, Ontario, by dumping snow into the Grand River, had broken its own pollution control by-law which prohibited waters containing a maximum of 15 mg/l of suspended solids being discarded into waterways. Since suspended solids in snow for this area ranged from 399 to 2,322 mg/kg of suspended solids Bandoni recommended to City Council not to dump snow into the Grand River. Whittle (1971) suggested that de-icing salt may actually increase highway accidents as, on salted roads, motorists have the illusion they are riding directly on pavement instead of a thin layer of melted water and hence tend to drive faster than they would otherwise. Moreover, dried salt spray on the windshield reduces the driver's visibility. This report presented to the Newton City Council, Massachusetts, recommends replacement of salt by sand.

4. ADDITIONAL STUDIES RECOMMENDED IN THE LITERATURE

From the available literature it is apparent that the environmental consideration of snow removal deserves further investigation of this problem. This part describes some studies which the literature indicates as needed to evaluate the environmental hazards associated with snow disposal and consequently to formulate a snow disposal policy.

To achieve this goal the following studies are required:

- (a) a study of the chemical quality of snow scraped from streets and highways. This is particularly important for areas where snow is dumped into nearby water bodies.
- (b) an extensive study to assess the current snow dumping practices and the development of "safer" means of ultimate snow disposal. The direct snow disposal into the Ottawa River (described in the preceding chapter), could be considered under this category.
- (c) further study on non-chemical melting of snow, including an environmental and economical evaluation of this operation.
- (d) a study of land disposal of snow to evaluate the types of soil suitable for land disposal of snow, changes of physical properties of soil, and effect of pollutants from snow, transport of pollutants following snow melt and the suitability of snow disposal location.

- (e) further studies on the environmental impact of chemicals from disposed snow and from de-icing mixtures. Studies are required on the effect on human health and on water biota of these pollutants. One of the results of this study could be the imposition of a limit on sodium in water meant for public supplies.
- (f) a study of sources of contaminants in snow; such a study could identify significant sources to be curtailed in order to reduce the amount of these pollutants in snow.
- (g) a study of the surface flow from drainages along highways and its possible control.
- (h) a detailed investigation of the potential hazards of additives mixed with de-icing chemicals.

BIBLIOGRAPHY

1. Abele, G., and G. Frankenstein. 1967. Snow and Ice Properties as Related to Roads and Runways in Antarctica. U.S. Army Cold Regions Research. Report No. 176.
2. Ackermann, W.C. et al. 1970. Some Long-Term Trends in Water Quality of Rivers and Lakes. *Environ. Sen.* 51.
3. Adair, T.H. 1961. Effect of an Inhibitor on the Corrosion of Auto Body Steel by De-icing Salt. Ontario Research Found.
4. Adam, J.R. and R.G. Semonin. 1970. Collection Efficiencies of Raindrops for Submicron Particulates. Atomic Energy Comm. Hwys. Series No. 22.
5. Adams, F.S. 1971. Salt, Assisted Accidents - A Question of Relative Safety, Proceedings: Street Salting, Urban Water Quality Workshop. Syracuse University.
6. Ahmed, N. 1972. Salt Pollution of Ground Water. Missouri Water Resources Research Center. Report No. B-093-MO(1).
7. Allan, L.L., E. Lorange and J. P. Lodge. 1970. Lead and Other Metal Ions in U.S. Precipitation. *Environ. Science and Technology* 4, 55.
8. Allen, H.E. and J. R. Kramer. 1972. Nutrients in Natural Waters. J. Wiley Inc.
9. Allison, L. E. 1964. Salinity in Relationship to Irrigation. *Advances in Agronomy* 16.
10. Allison, T. D. 1954. Melting of Deep Snow Packs by Conduction of Heat from the Ground. U.S. Army Corp. of Engineers' Report CW-171.
11. Amberg, C.R., et al. 1948. Rock Salt for Snow and Ice Removal New York State College of Ceramics.
12. American City (Journal). 1965. Side Effects of Salting for Ice Control 80, p. 33.
13. American Public Works Association. 1965. Snow Removal and Ice Control in Urban Areas. Project No. 114, 1.

14. American Public Works Association. 1969. Water Pollution Aspects of Urban Run-off. Federal Water Pollution Control Administration Contract No. WA 66-23.
15. American Public Works Association. 1950. Snow Removal Practices in Cities Under 200,000 Population and Snow and Ice Control. Chicago.
16. Anderson, B. 1948. The Apparent Thresholds of Toxicity of *Daphnia Magna* for Chlorides of Various Metals when Added to Lake Erie Water. Amer. Fish Soc. 78. p 96-113.
17. Ann Arbor's City Council. 1970. Recommendations on the Use of Salt as an Ice Control Agent on City Streets. Michigan.
18. Anon, J. E. 1957. Controlling Another River Pollutant: Salt. Eng. News Record, 159, 3.
19. Anon, J. E. 1970. Study of Effective Ice Control. Better Roads 40.
20. Anon, J. E. 1970. Town Finds a Way to Open Mountain Roads. Better Roads, 40.
21. Askwith, F. C. 1939. How Ottawa Handles Snow Problems. The Canadian Engineer, 40.
22. Asphalt Institute. 1963. The War Against Winter. Asphalt Institute Quarterly. Maryland.
23. Bain, E. C. 1970. Engineering Studies for Snow Removal. Snow Removal and Ice Control Research Report No. 115, 257.
24. Bandoni, F. 1972. Pollution Potential of Present Practice of Disposing Snow and Salt into the Grand River. City of Galt, Ontario. Engineering Report.
25. Bariea, J. and F.A.J. Armstrong, 1971. Contribution by Snow to the Nutrient Budget of Some Small Northwest Ontario Lakes. Limnology and Oceanography, 16.
26. Battelle Memorial Institute Columbus Laboratories. 1971. The Effects of Chemicals on Aquatic Life. Columbus, Ohio.
27. Batterton, J.C. 1970. Halotolerance in Blue-Green Algae. Univ. of Texas, Austin.
28. Bell, C. The Wonder of Snow. 1967. Hill and Wang, New York.
29. Berg, T.G.O. Collection Efficiency in Washout by Rain. Atomic Energy Comm. Hwy. Series No. 22.

30. Bergerou, A. 1932. Winter Maintenance of Roads in the Province of Quebec. *The Canadian Engineer*, 13-6.
31. Bernstein, L. 1958. Salt Tolerance of Grasses and Forage Legumes. USDA. *Agriculture Inf. Bull.* No. 194.
32. Bernstein, L. 1960. Salt Tolerance of Field Crops. USDA. *Agriculture Inf. Bull.* No. 217.
33. Bernstein, L. 1970. Calcium and Salt Tolerance in Plants. *Science*, 167.
34. Bernstein, L. 1965. Salt Tolerance of Fruit Crops. USDA. *Agriculture Inf. Bull.* No. 292.
35. Bernstein, L. 1959. Salt Tolerance of Vegetable Crops in the West. USDA. *Agriculture Inf. Bull.* No. 205.
36. Bertine, K.K. and E.D. Goldberg. 1971. Fossil Fuel Combustion and the Major Sedimentary Cycle. *Science*, 173.
37. Biles, G.H. 1918. Keep the Main Roads Open in Winter. *The Canadian Engineer*, 518-9.
38. Bilinski, H. and W. Stumm. 1973. Pb (II) Species in Natural Waters. Swiss Federal Institute of Technology, Switzerland.
39. Bishop, R.R. 1968. Corrosion of Motor Vehicles by De-icing Salt. *Road Research Laboratory's Report No. 148*, England.
40. Bloomfield, N.J. and S. Frieman. 1971. Snow Removal Depends Upon People. *Public Works*, 102.
41. Bodansky, M. and M.D. Levy. 1923. Some Factors Influencing the De-toxication of Cyanides in Health and Disease. *Int. Med.* 31.
42. Boecker, W.S. et al. 1971. Road Salt as an Urban Tracer. *Proceedings: Street Salting* Syracuse University.
43. Boies, D.B. and S. Bortz. 1905. Economical and Effective De-icing Agents for Use on Highway Structures. *NCHRP Report No. 19*.
44. Boutron, C. et al. 1972. Chemistry of Polar Snows. Estimation of Rates of Deposition in Antarctica. *Geochimica et Cosmochimica Acta*, France, 36.
45. Bouwer, H. 1969. Salt Balance, Irrigation Efficiency, and Drainage Design. *Jour. Irrig. and Drain. Div., Amer. Soc. Eng. Proc.* 95.

46. Bouwer, H. and R.C. Rice. 1968. A Salt Penetration Technique for Seepage Measurement. *Jour. Irrig. and Drain, Div., Amer. Civ. Eng. Proc.* 94.
47. Brandes, E.A. 1971. Search for Necessary Conditions for Heavy Snow on the East Coast. *Jour. of App. Meteorology*, 10.
48. Brandl, H. 1971. Changing the Physical Characteristic of Soil Using Chemicals. *Kultur. Flurbereinig, Austria*, 7, 12.
49. Brock, J.T. 1970. Attachment of Trace Substances on Atmospheric Aerosols. *Atomic Energy Comm. Hwys. Series No. 22*.
50. Bubeck, R.C. et al. 1971. Run-off of De-icing salt: Effect on Irondequoit Bay, Rochester, New York. *Science* 6, 1128-1131.
51. Bugher, R.D. 1967. Effects of Winter Storm Water Run-off on Vegetation and as a Factor in Stream Pollution. *Seventh Annual Snow Conf. Wisconsin*.
52. Burdick, G.E. and M. Lipschuetz. 1948. Toxicity of Ferro and Ferricyanide Solutions to Fish and Determination of the Cause of Mortality. *Amer. Fish Science*. 78.
53. Burns, B.D. 1970. The Use of De-icing Salts Within the Lake Ontario Drainage Basin (Effects and Benefits). *Ontario Water Resources Commission Report*.
54. Button, E.F. 1964. Influence of Rock Salt, Salt Used for Highway Ice Control on Natural Sugar Maples at one Location in Central Connecticut. *Connecticut State Highway Dept.*
55. Button, E.F. 1965. Ice Control Chlorides and Tree Damage. *Public Works*, 93, 3, 136ff.
56. Caffrey G.P. 1956. Plows, Salt and Promptness. *The American City*, 71.
57. The Canadian Engineer, (Journal) 1939. Snow Removal at Canada's Airports. 77.
58. The Canadian Engineer (Journal) 1938. Snow Removal is Profitable. 75.
59. The Canadian Engineer (Journal) 1939. \$3,100.00. Profit From Plowing. 77.
60. Canadian Municipal Utilities Manual. 1961. Winter Maintenance of Urban Streets. 99.

61. Cannon, H.L. and J.M. Bowles. 1962. Contamination of Vegetation by Tetraethyl Lead. *Science*, N.Y., 137.
62. Carlson, P.E. and J.S. Marshall. 1972. Measurement of Snowfall by Radar. *Jour. of App. Meteorology*, 11.
63. Carnduff, J.A. 1970. Report on Effect of Road Salting on Potable Water Supply. *Toronto Dept. of Works' Report*.
64. Carpenter, E.D. 1970. Salt Tolerance of Ornamental Plants. *American Nurseryman*, 131.
65. Carry, J.W. and H.F. Maryland. 1972. Salt and Water Movement in Unsaturated Frozen Soil. *Soil Science of America Proceedings*. 36.
66. Cassidy, N.G. 1971. Cyclic Salt and Plant Health Endeavour, 30.
67. Chapman, W.E. 1952. Design of Snow Melting Systems. *Heating and Ventilating* 49, 4, 96-102.
68. Charbonneau, R. 1969. Mathematical Model of Sun-Off Due to Snow Melt. *Nature*, 96.
69. Chonkar, P.K. et al. 1971. Seed Pelleting in Relation to Nodulation and Nitrogen Fixation by *Phaseolus Aureus* L. in a Saline Alkali Soil. *Plant and Soil*, 35.
70. Chow, T.J. et al. 1972. Lead Aerosol Baseline: Concentration at White Mountain and Laguna Mountain, California. *Science*, 178. p 401.
71. Chung, S.I., et al. 1971. Removal of Lead from Automobile Exhausts by Molten Salts. *Environmental Science & Tech.* 5.
72. Cinitron, G. et al. 1970. Consequences of Brine Pollution in the Bahia Fosforecente, Puerto Rico. *Limnology and Oceanogr.* 0015.
73. The City of Winnipeg. 1967. A Report on the Removal and Disposal of Snow in the City of Winnipeg. *Engineering Report*.
74. Clary, A.G. 1971. De-icing - A Public Works Director's Dilemma. *Proceedings: Street Salting*. *Urban Water Quality Workshop*, Syracuse University.
75. Clemens, H.P. and W.H. Jones. 1955. Toxicity of Brine Water From Oil Wells. *The American Fisheries Society 84th Annual Meeting*, Seattle, Washington, Ann Arbor, Mich.

76. Clemens, H.P. and J.C. Finnel. 1955. Biological Conditions in a Brine Polluted Stream in Oklahoma. *Trans. Em. Fish Soc.*, 85.

77. Clouth, G.W. 1933. Poisoning of Animals by Cyanides Present in Some Industrial Effluents. *Vet. Rec.* 13.

78. Clyde, C.D. 1931. Snow Melting Characteristics. *Utah Agri. Exp. Sta. Bull.* 231.

79. The Committee of Engineers and Technicians. 1964. *Snow and Ice Removal*. Warsaw, Poland.

80. Coombes, J.P. 1971. Facing Snow Emergencies. *Public Works*, 102.

81. Cottringer, P. and H.C. Kendell. 1923. The Use of Calcium Chloride as Protection Against Freezing of Concrete. *Concrete*, 22.

82. Croll, K. 1970. Principles of Snow Removal and Snow Removal Machines. *Highway Research Board's Special Report No.* 115.

83. Daily News, Columbus. 1971. Snow Heavy With Lead. Ohio.

84. Dana, M.T. Scavenging of Soluble Dye Particles by Rain. *Atomic Energy Comm. Symp.*

85. Das, S.K. 1971. Salt Tolerance of Some Agricultural Crops During Early Growth Stages. *Indian Jour. of Agr. Sci.*, 41.

86. Davidson, H. Pine Mortality Along Michigan Highways. *Journal Article No. 4723. Michigan Agricultural Expt. Station.*

87. Davidson, W.D. 1953. Ways to Win the Snow Battle This Year. *Civic Administration*, 15.

88. Davies, R. 1972. Where Have All the Metals Gone? *Water and Pollution Control* 110, 20, 19-20.

89. Davison, A.W. 1971. The Effects of De-icing Salt on Roadside Verges *Journal of Applied Ecology*, 8. P 555-561.

90. Dawton, G.W. and Eggert, C.V. 1957. Effect of High Sodium Chloride Concentration on Trickling Filter Slimes. *Sewage and Ind. Wastes*, 29, 11.

91. Dembiske, F.E. 1957. Snow Removal Operations in The Province of B.C. *Proceedings of Western Snow Conference, Santa Barbara, Calif.*

92. Desmarais, J. 1973. Personal Communications. J.L. Richards and Associates.
93. Deutsch, M. 1963. Ground Water Contamination and Legal Controls in Michigan. U.S. Dept. of Interior Report.
94. Dickinson, W.J. 1968. Snow and Ice Control - A Critical Look at its Critics. *Snow and Ice Control, Highway Research Record*, 48.
95. Dingle, A.M. 1970. Scavenging of Tracer in Severe Storms. *Atomic Energy Comm. Symp. Series No. 22*.
96. Dobrzanski, B. et al. 1971. Effect of Chemical Compounds Used for the Removal of Snow on the Soil Salinity of Warsaw City Green Spaces. *Glebozn*, 22.
97. Dobson, H.H. 1967. Principal Ions and Dissolved Oxygen in Lake Ontario. *10th Conference on Great Lakes Research*. 337-356.
98. Donahue, M.A. 1965. The Use and Effects of Highway De-icing Salts. *Legislative Research Council, Commonwealth of Mass.*
99. Dordukes, W.E. 1968. Tolerance of Various Turfgrass to Foliar Application of Road Salt. *Dept. of Agriculture, Ottawa*.
100. Douglass, A.H. 1920. Report on the Problem of Street Clearing and Snow Removal in the City of Minneapolis, Minnesota. *Minneapolis*.
101. Duke, T.W. et al. 1968. A Technique for Studying the Exchange of Trace Elements Between Estuarine Sediments and Water (Mathematical Model). *Journal of Limnology and Oceanography*, 13.
102. Dunnery, D.A. 1970. Chemical Melting of Ice and Snow on Paved Surfaces. *Highway Research Board's Special Report No. 115*.
103. Eaton, F.M. 1971. Salt Injury to Plants With Special Reference to Cations Versus Anions and Ions Activities. *Plant Soil*, 35.
104. Eidt, C.H. 1963. Winter Maintenance. *The Municipal World*, 323-7.
105. Englemann, R.J. and W.G.N. Slinn. 1970. Precipitation Scavenging. *Atomic Energy Comm. Symp. Series No. 22*.
106. Englemann, R.J. 1970. Scavenging Prediction Using Ratios of Concentrations in Air and Precipitation. *Atomic Energy Comm. Symp. Series No. 22*.

107. Environmental Protection Agency. 1972. Water Quality Criteria Data Book. 3.
108. Environmental Science and Technology. 1972. Computer Model Simulates Air Pollution Over Roads. 6.
109. Eshel, A. and Y. Waisel. 1972. Variations in Sodium Uptake Along Primary Roots of Corn Seedlings. Plant Physiology, 49.
110. Eskew, G.L. 1048. Salt, the Fifth Element. J.G. Ferguson and Associates.
111. Fadeeva, V.K. 1971. Effect of Drinking Water with Different Levels of Chlorides on Experimental Animals. USSR, Gig. San. 36.
112. Fanning, C.D. and L. Lyles. 1969. Salt Concentration of Rainfall and Shallow Groundwater Across the Lower Rio Grande Valley. Journal Geophysics and Resources, 69.
113. Feick, G. et al. 1972. Release of Mercury from Contaminated Freshwater Sediments by the Run-off of Road De-icing Salt. Science, 175, (4026) 1142.43.
114. Financial Post (Newspaper) 1965. Details of Expenditure of Department of Highways of Ontario. Toronto.
115. Fitzpatrick, J.R. 1970. Beehives Protect Snow Removal Salt and Prevent Water Pollution. American City. 85
116. Foglia D. and G.E. Scotto. 1966. Economic Aspects, Equipment and Organization of the Winter Maintenance of the Mail Roads of Italy. Turin, Italy.
117. Forbes, C.E. et al. 1970. Snow and Ice Control in California. Highway Research Board's Special Report No. 115.
118. Francois, L.E. and J.R. Goodim. 1972. Interaction of Temperature and Salinity on Sugar Beet Termination. Agronomy Journal, 64.
119. Fried, J.J. 1971. A Dispersion Model for a Quantitative Study of a Groundwater Pollution by Salt. Water Research 5.
120. Fromm, H.J. 1967. The Corrosion of Auto-body Steel and Effects of Inhibited De-icing Salts. Dept. of Highways, Ontario, 1967.
121. Fromm, H.J. 1971. Effects of De-icing Salts on the Environment Report No. IR43. Ontario Department of Transportation and Communications.

122. Fuguay, J.J. 1970. Scavenging in Perspective. Atomic Energy Comm. Symp. Series No. 22.
123. Gauseman, H.W. et al. 1972. Effects of Salt Treatments of Cotton Plants on Leaf Mesophyll Cell Microstructure. *Agronomy Journal*, 69.
124. Chorasky, S.R. et al. 1972. Salt Tolerance on Safflower Varieties During Germination. *Agronomy Journal*, 64.
125. Green, W. C. 1968. What are the Problems? Proceedings of the Symposium: Pollutants in the Environment. University of Connecticut.
126. Greenway, H. 1972. Salt Responses of Enzymes from Species Differing in Salt Tolerance. *Plant Physiology*, 49.
127. Grimm, A. 1960. A Snow and Ice Program that Works: Des Moines, Iowa. *The American City*, 75.
128. Grobelny, W.J. 1971. Snow Dump Survey - City of Thunder Bay. O.W.R.C. Report, Ontario.
129. Hales, J.M. et al. 1970. Washout of SO₂ from the Plume of a Coal-Fired Power Plant. Atomic Energy Comm. Symp. Series No. 22.
130. Hall, J.N. and S.P. La Hue. 1970. Effect of Salt on Reinforced Concrete Highway Bridges and Pavements. Highway Research Board's Special Report No. 115.
131. Hall, R. 1971. Injury on roadside trees: leaf injury on white cedar in relation to foliar levels of sodium and chloride. *Can. J. of Botany* 49.
132. Hall, R., and G. Hofstra. 1972. Effects of De-icing of Salt in eastern white pine: foliar injury, growth suppression and seasonal changes in foliar concentrations of sodium and chloride. *Can. J. Forest Research* 2.
133. Hall, S.K. 1972. Lead Pollution and Poisoning. *Environmental Science & Technology*, 6, (1), 31-35.
134. Hamblin, G.D. 1959. Salt is Still the Best. *The American City*, 74.
135. Hanes, R.E. 1970. Salt Tolerance of Trees and Shrubs to De-icing Salts. National Co-operative Highway Research Program Report No. 335. Highway Research Board.

136. Hann, R.W. 1970. Mathematical Modelling of Gulf Coast Estuaries. *Water Resources Bull.* 6.
137. Harris, J.C. et al. Chemical Means for Prevention of Accumulation of Ice, Snow and Slush and Runways. Monsanto Research Corp. Report No. 65-13.
138. Hastings, L. 1972. Fallout of Sodium Sulphate near a Kraft Mill. *Atmospheric Environment*, 6.
139. Hawkins, R.H. 1971. Street Salting and Water Quality in Meadow-brook. Syracuse University.
140. Hayward, H.E. and L. Bernsteine 1970. Plant Growth Relationship on Salt Affected Soils. *Botanical Review*, 95.
141. Hedges, W.E. Emergency Plan Saves the Day. *The American City*, 75.
142. Hemphill, D.D., (Editor). 1969. Trace Substances in Environmental Health. University of Missouri Environmental Health Centre.
143. Hendrich, R.L. et al. 1971. Application of Environmental Analysis to Watershed Snowmelt. *Jour. of App. Meterology*, 10.
144. Hidy, G.M. 1970. Theory of Diffusive and Impactive Scavenging. *Atomic Energy Comm. Symp. Series No. 22*.
145. Highway Research Board. 1967. Effects of De-icing Salts on Roadside Soils and Vegetation. Washington.
146. Highway Research Board. 1970. Effect of De-icing Compounds on Vegetation and Water Supplies. Report No. 16.1, Washington, D.C.
147. Highway Research Board. 1970. A Study of Salt Pollution of Soil by Highway Salting. Report No. 193, Washington, D.C.
148. Highway Research Board. 1970. Metabolic Index as a Diagnostic Tool in Tree Health Determination. Report No. 335, Washington, D.C.
149. Highway Research Board. 1970. Snow and Ice Control Research. Report No. 115, Washington, D.C.
150. Highway Research Board. 1965. Economical and Effective De-icing Agents for Use on Highway Structures. Washington, D.C.

151. Highway Research Board. 1970. Protective Coatings to Prevent Deterioration of Concrete by De-icing Chemicals. Washington, D.C.
152. Highway Research Board. 1970. Effect of De-icing Salts on Water Quality and Biota. Report No. 91. Washington, D.C.
153. Highway Research Board. 1971. Facts You Should Know About Effects of De-icing Salt on the Environment. Supplement to the report No. 91, American Public Works Assoc.
154. Highway Research Board. 1967. Environmental Considerations in Use of De-icing Chemicals - 5 Reports. Highway Research Record, No. 193. Washington, D.C.
155. Highway Research Board. 1970. Non-Chemical Methods of Snow and Ice Control on Highway Structures. Washington, D.C.
156. Highway Research Board. 1970. Sodium Chloride Uptake in Grasses as Influenced by Fertility Interaction. Report No. 335.
157. Highway Research Board. 1970. Salt Tolerance of Trees and Shrubs to De-icing Salt. Report No. 335.
158. Highway Research Board. 1967. The Relationship of Road Salt Applications to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways. Report No. 193.
159. Highway Research Board. 1967. Pollution Aspects Associated with Chemical De-icing. Report No. 193.
160. Highway Research Board. 1967. Effect of Sodium Chloride on Grasses for Roadside Use. Report No. 193.
161. Hill, D. H. 1971. Pollution .. the No-Lead Myth. Hot Rod, 2.
162. Hodgins, E.N. 1971. Snow Plowing at 60 Miles per Hour. Public Works, 102.
163. Holmes, F.W. 1961. Salt Injury to Trees. Phytopathology 51
164. Holmes F.W. and T.H. Backer. 1966. Salt Injury to Trees, Sodium and Chloride in Roadside Sugar Maples in Massachusetts. Phytopathology, 56, 6, 633-636.
165. Holster, W. 1956. Snow Removal Needs New Ideas. The American City, 71.

166. Horton, M.L. Salinity Above a Water Table as Affected by Rainfall and Irrigation. Water Resources Inst. Report. South Dakota University.
167. Hovey, G.E. et al. 1967. 1966-67 Urea Test Program. Centre Exper. Prov. Establish, Ottawa, Ontario. Report No. 1958.
168. Hubbard, W.C. 1963. Modernized Winter Maintenance Operations Bring Results. Public Works, 94.
169. Hughmanik, R.N. 1971. Highway Chlorides - Menace or Manna? Public Works, 102.
170. Huling, E.E. and T.C. Hollocher. 1972. Groundwater Contamination by Road Salt: Steady-State Concentrations in East Central Massachusetts. Science, 176. (4032) 288-290.
171. Hunter, L.M. 1918. Snow Clearing and Removal in Ottawa. The Canadian Engineer, 34.
172. Hutchinson, F.E. 1970. Environmental Pollution from Highway De-icing Compounds. Journal of Soil and Water Comm. 25.
173. Hutchinson, F.E. 1957. A Treatise on Limnology, Vol. 1. John Wiley and Sons, Inc., N.Y.
174. Hutchinson, F.E. 1966. The Influence of Salts Applied to Highways on the Levels of Sodium and Chloride Ions Present in Water and Soil Samples. Progress Report No. 1. Project No. R-1086-8
175. Hutchinson, F.E. 1971. The Effect of Highway Salt on Water Quality in Selected Maine Waters. Syracuse University.
176. Hutchinson, F.E. 1969. Effect of Highway Salting on the Concentration of Sodium and Chloride in Private Water Supplies. Research in Life Sc., 13.
177. Hutchinson, F.E. 1966. Accumulation of Road Salt Ions in Soils Along Maine Highways. Maine Farm Research.
178. Hutchinson, F.E. 1971. Dispersal of Sodium Ions in Soil. Maine State Highway Commission Record, 1971.
179. Hutchinson, F.E. 1968. Effects of Highway Salting on the Concentration of Sodium and Chloride in Rivers. Res. in the Life Sciences.

180. Hutchinson, F.E. and B.E. Olson. 1967. The Relationship of Road Salt Applications to Sodium and Chloride Levels in the Soil Bordering Major Highways. *Highway Research Record* 193.
181. Hyder, S.Z. 1970. Effect of Calcium on Phosphorus Uptake and Metabolism in Plant Grown at High Sodium Chloride Concentration. *Pakistan, Nukleus*, 7.
182. Ichihara, K. and M. Mizoguchi. 1970. Skid Resistance of Snow or Ice Covered Roads. *Highway Research Board's Special Report No. 115*.
183. Idaho Department of Highways. 1966. Maintenance Manual, Boise, Idaho.
184. Ingols, R.S. 1970. Study of Sludge Digestion with Sodium Chloride and Sulfate. *U.S. Clearinghouse Fed. Sci. Tech. Inf. No. 196732*.
185. International Joint Commission. 1969. Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.
186. Isaac, P.C.G., 1957. Treatment of Trade Waste Waters and Prevention of River Pollution : Proceedings. Kings College, Newcastle-upon-Tyne, England.
187. Jackson, D.D. 1905. The Normal Distribution of Chlorine in the Natural Waters of New York and New England. *U.S. Geol. Survey Water Supply*, 144.
188. Jellimer, H.H.G. 1970. Ice Adhesion and Abhesion. *Highway Research Board's Special Report No. 115*.
189. Jiusto, J.E. and G.E. Bosword. 1971. Fall Velocity of Snowflakes. *Jour. of App. Meteorology*, 10.
190. Johansson, A. 1970. Urea as a De-icing Agent. *Cement Institute, Sweden*.
191. Johnson, L.F. 1946. Ice Prevention on New Hampshire Highways. *Eng. News Record*, 4.
192. Jones, J.R.E. 1941. A Study in the Relative Toxicity of Anions with *Polycetes Nigra* as the Test Animal. *Journal Esp. Bio.*, 18.
193. Judd, J. H. 1969. Effect of Salt Run-off From Street De-icing on a Small Lake. *Thesis, University of Wisconsin*.
194. Judd, J.H. 1970. Lake Stratification Caused by Run-off From Street De-icing. *Water Research*, 4.

195. Jumikis, A.R. 1970. Aerodynamic Snow Fences to Control Snow-drifting on Roads. Highway Research Board's Special Report No. 115.

196. Karaban, G.L. 1955. Equipment for Snow Removal. Ministry of the Public Works, Moscow, USSR.

197. Karsten, A. 1936. Effects of Cyanide on Black Hills Trout. Journal Amer. Waterworks Assoc. 23.

198. Keiss, E.W. 1960. Planning and Organization Make Up For a Lack of Equipment. The American City, 75.

199. Kemper, W.D. and L. Noonan. 1970. Run-off as Affected by Salt Treatments and Soil Texture. Soil Science Soc. Amer. Proc. 34.

200. Kerker, M. et al. 1970. Collection Efficiency of Water Droplets in Aerosols. Atomic Energy Comm. Symp. Series No. 22.

201. Kincannon, D.F. and A.F. Gaudy, Jr. 1968. Responses of Biological Waste Treatment Systems to Changes in Salt Concentrations. Bio-tech. and Bio-eng., 10. p. 483-496.

202. Kinoshita, S. and E. Akitaya. 1970. Classification of Snow and Ice on Roads. Highway Research Board's Special Report No. 115.

203. Kinoshita, S. and E. Akitaya. 1969. Snow and Ice on Roads. Low Temp. Science, Ser. A., 27.

204. Knobel, A. 1957. Snow Clearance Problems on Swiss Roads. Proc. Inst. of Civil Eng., London, 8.

205. Knox, W.K. 1916. Nitrogen and Chlorine in Rain and Snow. Chemical News, 113.

206. Kortzeborn, R.N. and F.F. Abraham. 1970. Scavenging of Aerosols by Rain. A Numerical Study. Atomic Energy Comm. Symp. Series No. 22.

207. Kotheimer, J. et al. 1965. Salt Injury to Roadside Trees. Forest Notes, 85.

208. Kramer, J.R. 1972. Unpublished Data. McMaster University, Hamilton, Ont.

209. Kunkle, S.H. 1972. Effects of Road Salts on a Vermont Stream. Journal of the American Waterworks Assoc., 64. 5, 290-295.

210. Kuroiwa, D. 1962. A Study of Ice Sintering, U.S. Army Cold Regions Research Report No. 86.
211. Kyster, J.O. 1971. Brine Solution Removes Stubborn Ice. Public Works, 1
212. LaBarre, J.N. et al. 1972. Lead Contamination of Snow. Report, Ontario Ministry of the Environment.
213. LaBarre, J.N. et al. 1972. Chloride and Lead Distribution in Urban Snow. Report, Ontario Ministry of the Environment.
214. LaCasse, N.L. and A.E. Rich. 1964. Maple Decline in New Hampshire Phytopathology 54.
215. LaHaye, P.A. 1970. Calcium and Salt Tolerance of Plants Science, 0167.
216. LaHaye, P.A. and E. Epstine. 1971. Calcium and Salt Toleration by Beau Plants. Physiologia Plantarum, 25.
217. Lang, C.H. and W.E. Dickenson. 1964. Snow and Ice Control with Chemical Mixtures and Abrasives. Highway Research Record. No. 61.
218. La Vergne, De, P. 1971. Salt and It's Source: Livingston and Wyoming Countries. Proceedings: Street Salting. Syracuse University.
219. Lehmann, C. and L.F. Fisherei. 1936. The Effect on Fish of Effluents Containing Cyanide. Jour. Am. Waterworks Assoc., 23.
220. Lennon, J.T. 1967. Cost Analysis of Snow and Ice Control Operations. American Public Works Association Year Book.
221. Lhermitte, R.M. 1970. Radar Observations of Connective Storm Circulation and Relation to Precipitation Scavenging. Atomic Energy Comm. Symp. Series No. 22.
222. Linzon, S.N. 1971. Highway Salting and Trees. Ontario Forest, 3.
223. Linzon, S.N. 1973. Ministry of the Environment. Personal Communications.
224. Linzon, S.N. 1973. Some Effects of Particulate Matter on Vegetation in Ontario. Proc. Third. Int. Clean Air Congress. Dusseldorf, Germany.
225. Lipinski, K. 1970. Sources of Salt in Surface Waters Possibilities of Reduction of Salt Load, Chemicals From Sea Water and Other Saline Waters. Poland, Cent. Lab. Chem. Ores. 1.
226. Lochard, E.E. et al. 1955. The Effect of Water Impurities on The Flavour of Brewed Coffee. Food Research, 20.

227. Lockwood, R.K., (Editor). 1965. Snow Removal and Ice Control in Urban Areas. American Public Works Association. Project No. 114, 1.

228. Lucia, F.J. 1969. Snow Removal and Ice Control in Urban Areas. American Public Works Association Year Book, Chicago.

229. Lumis, G.P. and G. Hofstra. 1971. Salt Damage to Roadside Plants. Ont. Dept. Agriculture and Food, Factsheet 690.

230. Her Majesty's Stationery Office. 1968. Salt Treatment of Snow and Ice on Roads. London.

231. Her Majesty's Stationery Office. 1963. Winter Building, Ministry of Public Buildings and works. London.

232. Her Majesty's Stationery Office. 1964. Effects of Polluting Discharges on the Thames Estuary. Thames Survey Committee. London.

233. Mammel, F.A. 1972. We are Using Salt-Smarter. The American City. 87.

234. Mammel, F.A. 1970. The Public Works Official and the Environmentalists. Report to the City Council, Ann Arbor, Michigan.

235. Marsters, G.F. et al. 1971. Urban Snow Removal in Canada. Dept. of Mech. Eng., Queen's University.

236. Mason, H.F. 1971. Heat Pipe; Economical Snow Melting Device? Heating-Piping, 43.

237. Massachusetts Legislative Council, The, 1965. The Use and Effects of Highway De-icing Salts. Highway Res. Abstract.

238. McConnel, H.H. and J. Lewis. 1972. Add Salt to Taste. Environment 14.

239. McLeod, U.W. 1962. What's Going on in Highway Research. The Municipal Worls, 72

240. Meier, M. 1969. Present Status of Snow and Ice Hydrology. Proc. Workshop on Snow and Ice Hydrology Colorado State University.

241. Mellor, M. 1970. A Brief Review of Snowdrifting Research. Highway Research Board's Special Report No. 115.

242. Mercier, P.E. 1916. Snow Removal in Montreal. The Canadian Engineer, 31.

243. Michigan Municipal League. 1959. Snow Removal and Ice Control Practices in Michigan Municipalities. Michigan.

244. Miller, E.L. 1970. Models for Predicting Snow Removal Cost and Chemical Usage. Highway Research Board's Special Report No. 115.

245. Miller, W.C. 1965. Snow Removal and Ice Control. The Municipal Works, 75.

246. Milwaukee Journal, 1970. What is Highway Salt Doing to Us. Milwaukee, Wisconsin.

247. Minsk, L.D. 1971. A Short History of Man's Attempts to Move Through Snow. U.S. Army National Command, Cold Region Research and Engineering Laboratory Tech. Report No. 128.

248. Minsk, L.D. 1964. Survey of Snow and Ice Removal Techniques. U.S. Army National Command, Cold Region Research and Engineering Laboratory Tech. Report No. 128.

249. Monk, R.W. 1962. Tolerance of Some Trees and Shrubs to Saline Conditions. Proc. Am. Soc. Hort. Sc., 81.

250. Monk, R.W. and H.H. Wiebe. 1961. Salt Tolerance and Protoplasmic Salt Hardiness of Various Woody and Herbaceous, Ornamental Plants. Plant Physiology, 38.

251. Moody, E.G. 1948. Snow and Ice Removal Practices in Michigan Municipalities. Michigan Municipal League.

252. Moore, E.W. 1950. Tolerable Salt Concentrations in Drinking Waters. Committee on San. Eng. and Environment.

253. Moore, E.W. 1952. Physiological Effects of the Consumption of Saline Drinking Water. National Research Council.

254. Mosevich, M.V. 1971. Action of Some Salts and Their Ions on Self-Purification Processes in the Water of Fish Hatcheries. USSR. Gosniorkh, 16.

255. Mosin, V.I. 1972. A Study of Some Characters of Metabolism of Scotch Pine Seeds During Storage in Snow. Biological Abstracts Inc. Copyright.

256. Municipal Engineer, (Journal). 1916. Systematic Snow Removal in New York City. 50.

257. Munn, R.E. 1971. On The Meteorological Interpretation of the Chemical Composition of Monthly Precipitation Samples. Atmospheric Environ. Service Report No. AC-10. Toronto, Ontario.

258. Nakayama, F.S. 1966. Deflocculation of Soil Materials by Sodium Salts. Soil Science, 102.

259. National Academy of Science. 1971. Airborn Lead in Perspective, NRC. Washington, D.C.

260. National Canners Association. 1971. Reduction of Salt Content of Food Processing Liquid Waste Effluent. Berkeley, Calif.

261. National Research Council, Ottawa. 1964. Snow Removal and Ice Control. NRC No. 8146. Tech. Mem. No. 83, Ottawa.

262. National Research Council, Ottawa. 1967. Manual of Snow Removal and Ice Control in Urban Areas. NRC. No. 9904, Tech. Mem. No. 93.

263. National Research Council, Ottawa. 1971. Run-off From Snow and Ice. Symposium No. 8, 1.

264. Nichols, R.J. and W.I. Price. 1956. Salt Treatment for Clearing Snow and Ice. The Surveyor, 115.

265. O'Connor, D.J. and J.A. Mueller 1970. A Water Quality Model of Water in the Great Lakes. Journal of the San. Eng. Div. Proc. of A.S.C.E. 96, S.A. 4. 955-975.

266. Odberg, E. 1959. Modern Snow Removal Methods. The Municipal World, 61.

267. O'Learly, J.W. and Prisco. 1970. Response of Osmotically Stressed Plants to Growth Regulations. Advancing Frontiers in Plant Sciences, 25.

268. O'Leary, T.J. 1960. Snow Removal and Ice Control. American Public Works Assoc. Year Book, Chicago.

269. Olsen, S.P. 1966. The Economics of Snow Disposal. Dept. of Roads, City of Montreal.

270. Ontario Ministry of the Environment. 1972. Guidelines and Criteria for Water Quality Management in Ontario.

271. Ontario Ministry of Transportation and Communication. 1972. Operating Instruction-Winter Maintenance Operations. Report.

272. Ontario Water Resources Commission. 1971. De-icing Salts as a Source of Water Pollution. Water Quality Surveys Branch. Report, Toronto, Ontario.

273. Ontario Water Resources Commission. 1971. De-icing and Snow Disposal. Report, Toronto, Ontario.

274. Owenby, C.R. and D.A. Kee. 1967. Chlorides in Lake Erie. 10th Conference on Great Lakes Research.

275. Panarase, W.C. 1970. Chemical De-icing of Concrete. Portland Cement Association, Chicago.

276. Parry, G.E. 1969. Minimum Road Temperatures. Meteor. Magazine, London, 98.

277. Pecore, R. 1963. Seventeen Hour Parking Ban Aids Snow Plowing. The American City, 78.

278. Peirce, A.W. 1968. Studies on Salt Tolerance of Sheep. Australian Journal of Agricultural Research, 19.

279. Pierson, D.H. et al. 1973. Trace Elements in the Atmospheric Environment. Nature, 241. 252-256.

280. Perkins, R.W. et al. 1970. In Cloud Scavenging Analysis from Cosmogenic Radionuclide Measurements. Atomic Energy. Comm. Symp. Series. No. 22.

281. Peterson, K.R. and R.V. Peterson. 1970. Precipitation Scavenging in a Large Cloud Diffusion Code. Atomic Energy Comm Symp. Series. No. 22.

282. Petrenchuk, P.O. and E.S. Selezneva. 1970. Chemical Composition of Precipitation in Regions of the Soviet Union. Jour. Geographic Res. 75.

283. Pils, F.W.F. 1951. Fresh Water Problems in Connection With Soil and Water Salination in The Western Part of the Netherlands. Bio-abstract No. 18221, 25.

284. Pollock, S.J. 1971. Salt Contamination of the Water Supply at Auburn, Massachusetts. U.S. Dept. of Interior, Report.

285. Pollock, S.J. 1972. Effects of Highway De-icing Salts on Ground Water and Water Supplies in Massachusetts. U.S. Dept of Interior, Report.

286. Posey, C.J. 1970. Plow Clean Without Scraping. Highway Research Board's Special Report No. 115.

287. Potter, J.G. 1962. Changes in Seasonal Snowfall in Cities. Canadian Geographer, 42.

288. Price, M.J. 1949. Some Effects of Salt Water on Soil Fertility. Soil Science Soc. Amer. Proc. 14.

289. Prior, G.A. 1968. Salt Migration in Soil Proceedings of the Symposium: Pollutants in the Roadside Environment. University of Connecticut.

290. Pryzby, S.R. 1971. De-icing With Salt-Some Pros and Cons. Public Works, 98.

291. Public Works in Canada, (Journal). 1963. Year-Round Preparedness Keeps Queen Province 'Cold War Army' Fit for Service. 11.

292. Quasim, S.F. et al. . The Influence of Salinity on the Rate of Photosynthesis and Abundance of Some Tropical Phytoplankton. Cochin, India.

293. De Quervain, M.R. 1950. Snow and Ice Problems in Canada and the U.S.A. Technical Report No. 5. Ottawa.

294. Radke, F.L. et al. 1970. Interactions of Cloud Condensation Nuclei With Cloud and Precipitation Elements. Atomic Energy Comm. Symp. Series No. 22.

295. Radke, F.L. et al. 1970. Interactions of Cloud Condensation Nuclei With Cloud and Precipitation Elements. Atomic Energy Comm. Symp. Series. No. 22.

296. Rahn, P.H. 1968. Movement of Dissolved Salts in Ground Water Systems. Proceedings of the Symposium: Pollutants in the Environment. University of Connecticut.

297. Rancitelli, A. et al. 1970. Stable Elements of the Atmosphere as Tracers of Precipitation Scavenging. Atomic Energy Comm. Symp. Series. No. 22.

298. Ravikovich, S. and D. Yoles. 1971. The Influence of Phosphorus and Nitrogen on Millet and Clover Growing in Soils Affected by Salinity. Plant and Soil 35.

299. Reich, F.R. and B.P. Hildebrand. 1970. Pulsed-Laser Holography for Analysis of Particle Size and Distribution. Atomic Energy Comm. Symp. Series No. 22.

300. Reiguam, H. 1970. European Interest in Acidic Precipitation. Atomic Energy Comm. Symp. Series No. 22.

301. The Resources Agency of California State Water Quality Control Board. 1963. Water Quality Criteria.

302. Rheinfrank, W.J. 1953. Procedures for the Removal of Light and Heavy Snows. The American City, 67.

303. Rich, A. E. 1968. Effect of De-icing Chemicals on Woody Plants Symposium: Pollutants in the Environment. University of Connecticut.

304. Rich, A.E. and N.L. Lacasse. 1963-64. Salt Injury to Roadside Trees. Forest Notes, 83.

305. Richards, J.L. and Associates. Labrecque, and Vezina and Associates. 1972. 20 Year Study on Snow Disposal in The Regional Municipality of Ottawa-Carleton and the Outaouais Regional Community. Report to the Committee on Snow Disposal, Ottawa.

306. Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Dept. of Agriculture Handbook No. 60, Washington, D.C.

307. Richards, T.L. and V.S. Denco, 1963. The Role of Lake Effect Storms in The Distribution of Snowfalls in Southern Ontario. Ontario Dept. of Transport, Toronto, Ontario.

308. Richter, C.P. and A. MacLean. 1939. Salt Taste Threshold of Humans. Am. Jour. Physiol., 126.

309. Ristavovic, B. 1969. Sodium Chloride Tolerance of Some Dominant Bacteria and Actinomycetes From Fresh Water, Brackish Water and Marine Habitats. Yugoslavia, Microbiology, 6.

310. Rivers and Lake Commission. 1962. The Effect on the Madison Lakes of Chemicals Used for Ice Control on the Streets and Highways. Report, Wisconsin.

311. Roads and Streets, (Journal). 1930. Equipment for Snow Removal. 70, 63.

312. Robbins, C.A. 1936. Winter Maintenance of Ontario Highways. *The Canadian Engineer*, 71.

313. Robbins, C.A. 1932. Winter Maintenance of Public Highways. *The Canadian Engineer*, 63.

314. Roberts, E.C. and E.L. Zybura. 1967. Effect of Sodium Chloride on Grasses for Roadside Use. *Highway Research Board Report*.

315. Rozbicki, R. 1969. Roads Maintenance in Winter. *Warsaw, Poland*.

316. Rudolphs, W. 1919. Influence of Sodium Chloride Upon the Physiological Changes of Living Trees. *Soil Sci.*, 8.

317. Ruge, U. 1972. Tree Death from Ice-Melting Salts. *Germany, Umschau*, 72.

318. Ruhling, A. and G. Tyler. 1968. An Ecological Approach to the Lead Problem. *Bot, Notiser*, 121. 321-342.

319. Rush, R.J. 1971. Snow Disposal by City of Kitchener in Sanitary Sewer at Kent Avenue. *Engineering Dept. Engineering Report*.

320. Ryling, R. W. 1961. A Preliminary Study of the Distribution of Saline Water in the Bedrock Aquifers of Eastern Wisconsin. *U.S. Geolog. Survey Report, Wisconsin*.

321. Saini, G.R. 1971. Comparative Effect of Gypsum and Limestone on Drainage and Salt Removal From Coastal Alluvial Soils of New Brunswick (Canada) Movement. *Plant Soil*, 34.

322. Salt Institute. 1971. Effect of De-icing Salt on the Environment. *Inf. Bull., Virginia*.

323. Salt Institute. 1971. De-icing Salts and the Environment Report, *Virginia*.

324. Salt Institute. 1965. Highway Salt and Roadside Vegetation. *Massachusetts Highway Salt Study*.

325. Salt Institute. 1967. Storing Road De-icing Salt. *Virginia*.

326. Salt Institute. 1968. The Snow Fighter's Salt Storage Handbook. *Virginia*.

327. Sauer, G. Damaging by De-icing Salts to Plantings Along the Federal Highways.

328. Saunders, C.P.R. et al. 1970. Continuous Charged Cloud-Particle Sampler. Atomic Energy Comm. Symp. Series No. 22.

329. Sawyer, C.N. 1960. Chemistry for Sanitary Engineers. McGraw-Hill, New York.

330. Schaedel, P. 1972. Measurement of Salt Content on Roadways and of Soil Salting Adjacent to a Highway. German Federal Institute Road Research Record.

331. Schaefer, P.A. 1970. Compaction or Removal of Wet Snow by Traffic. Highway Research Board's Special Report No. 115.

332. Scheidt, M.E. 1967. Environmental Effects of Highways. Journal of Sanitary Eng. Div., A.S.C.E. 93. 5A5, 17-25.

333. Schmassmann, H. 1971. Quantitative Evaluation of NaCl Marking in Ground Water Streams Flowing Through Gravel. Gas, Wasser, Ab. 51.

334. Schneider, T.R. 1962. The Calculation of the Amount of Salt Required to Melt Ice and Snow on Highways. National Research Council, Technical Translation 1004.

335. Schraufnagel, F.H. 1965. Chlorides. Committee on Water Pollution, Madison, Wisconsin.

336. Schulz, M. 1973. Environment Canada, Personal Communications.

337. Shalman, D.A. 1969. A Review of Snow Removal Equipment. Moscow, USSR.

338. Sharma, O.M. et al. 1970. Salt Tolerance of Different Varieties of Wheat at Germination. Indian Journal, Agri. Sci. 40.

339. Sharp, R.W. 1970. Road Salt as a Polluting Element. Special Environment Release No. 3. Twin Cities, Minnesota.

340. Shear, C.B. 1970. Calcium and Salt Tolerance of Plants. Comments, Science, 0167.

341. Sherl, C.A. 1966. Theoretical Aspects of Snow Melting. Proceedings 6th Annual North American Snow Conf. Montreal.

342. Shortle, W.C., J.B. Kottheimer and A. E. Rich. 1972. Effect of Salt Injury on Shoot Growth of Sugar Maple, *Acer saccharum*. Plant Disease Rptr. 56.

343. Sinclair, S.M. 1973. Ontario Ministry of Transportation and Communications, Personal Communications.

344. Slinn, W.G.N. and J.M. Hales. 1970. Phoretic Processes in Scavenging. Atomic Energy Comm. Symp. Series. No. 22.

345. Smith, H.A. 1968. Effect of De-icing Compounds on Vegetation and Water Supplies. 8th Annual North American Snow Conference, Cincinnati.

346. Smith, H.A. 1971. Environmental Effects of Snow Removal and Ice Control Programs. Eleventh Annual Snow Conference, Chicago, Illinois.

347. Smith, O.M. 1944. The Detection of Poisons in Public Water Supplies. Water Works Engineering, 97.

348. Smith, W.H. 1970. Salt Contamination of White Pine Planted Adjacent to an Interstate Highway. Plant Disease Rptr. 54.

349. Soderlund, G. 1970. Physicochemical and Microbiological Properties of Urban Storm Water Run-off. Fifth International Water Poll. Conf., San Francisco.

350. Sood, S.K. and M.R. Jackson. 1970. Scavenging by Snow and Ice Crystals. Atomic Energy Comm. Symp. Series No. 22.

351. State of Oklahoma Highway Department. 1964. Maintenance Manual.

352. Steffe, D.H. 1970. Concentration Variation of Some Trace Metals in Precipitation from Great Plains Thunderstorms. Atomic Energy Comm. Symp. Series, No. 22.

353. Stevenson, C.M. 1968. An Analysis of the Chemical Composition of Rainwater and Air over the British Isles and Eire for the Years 1959-64. Journal Meteor. Soc., 94.

354. Strong, F.C. 1944. A Study of Calcium Chloride Injury to Roadside Trees. Michigan Agr. Exp. Sta. Bull. 27.

355. Struzeski, L., (Editor). 1971. Environmental Impact of Highway De-icing. Environmental Protection Agency's Report.

356. Sullivan, R.H. 1967. Effect of Winter Storm Run-off on Vegetation and as a Factor in Stream Pollution. 7th Annual North American Snow Conference, Milwaukee.

357. Summers, P.W. 1970. Scavenging of SO₂ by Convective Storms. Atomic Energy Comm. Symp. Series No. 22.

358. Szaboles, I. and K. Darab. 1968. Salt Balance and Salt Transport Process in Irrigated Soils. Hungarian Acad. Sci. International Soil Sci., 1.

359. Tanaka, Y. 1970. Snow-Removing Performance of the Snowplow Truck. Highway Research Board's Special Report No. 115.

360. Taylor, F.B. 1971. Trace Elements and Compounds in Water. Jour. AWWA. 63, 11, 728-733.

361. Taylor, G.E. 1958. Street Cleaning and Snow and Ice Removal. Year Book, Chicago,

362. Technical Task Force, Toronto 1972. Report on Snow Disposal in the Metropolitan Toronto Area. Ministry of the Environment, Ontario.

363. Theakston, F.H. 1970. Model Technique for Controlling Snow on Roads and Runways. Highway Research Board's Special Report No. 115.

364. Thomas, L.K. 1967. Road Salt (Sodium Chloride) Injury to Kentucky Bluegrass. Highway Research Record No. 161.

365. Thomas, L.K. 1965. A Quantitative Microchemical Method for Determining Sodium Chloride Injury to Plants. U.S. Department of Interior Report.

366. Thomas, L.K. and G.A. Bean. 1965. Winter Rock Salt Injury to Turf. National Capital Region, National Park Service, Department of Interior Report.

367. Thomas, M.K. 1964. A Survey of Great Lakes Snowfall. Seventh Conf. on Great Lakes, Toronto.

368. Trainer, D.O. and L. Kasted. 1960 Salt Poisoning in Wisconsin Wildlife. Journal of the Am. Vet. Med. Assoc. 136, 1.

369. Trudeau, R.T. 1967. Winter Maintenance in the Laurentians - Expensive but Essential. Public Works, 98.

370. Tsuchiya, R. and M. Inque. 1970. Current Research on Snow Removal and Ice Control on Roads in Japan. Highway Research Board's Special Report No. 11.

371. Udovenko, G.V., and L.A. Sehushina, 1970. Productivity, Accumulation of Salts and Aqueous - Osmotic Properties of Plants With Pure and Mixed Salinization of the Soil. Agrochemistry, USSR.

372. Upchurch, S.B. and D.C.N. Robb. 1972. Mathematical Models: Planning Tools for the Great Lakes. Water Resources Bulletin 8.

373. United States Army - Corp of Engineers. 1960. Run-off From Snow Melt. Manual EM-1110-2. 1406.

374. United States Bureau of Yards and Docks. 1953. Snow Removal. Washington.

375. United States Department of Interior. 1969. Water Pollution Aspects of Urban Run-off for the Federal Water Pollution Control Administration. American Public Works Assoc.

376. United States Federal Aviation Agency. 1964. Benefit Cost Analysis of Airport Snow, Ice and Slush Removal. Project No. 415-25.

377. Utah State University. 1972. Bibliography of Literature Pertinent to Snow Pack Management. Logan, Utah. USA.

378. Vali, G. 1970. Entry of Freezing Nuclei into Precipitation. Atomic Energy Comm. Symp. Series. No. 22.

379. Van Akkeren, I. 1960. A Snow Fighting Plan is Essential. The American City, 75.

380. Van Loon, J.C. 1972. The Snow Removal Controversy. Water and Pollution Control 110, 11, 16-20.

381. Wagner, K. 1938. The Melting Process from the Standpoint of Geophysics. Nature Historic Museum, Vienna, Austria.

382. Walker, W.H. 1970. Salt Piling - A Source of Water Supply Pollution. Pollution Eng., 2,3,20-33.

383. Walker, W.H. 1970. Limiting Road Salt Pollution of Water Supplies. Illinois State Water Survey Report.

384. Walton, G.S. 1969. Phytotoxicity of NaCl and CaCl₂ to Norway Maples. Phytopathology, 59.

385. Washer, L. 1962. Details Count in Snow Control. The American City, 77.

386. Watkins, L.H. 1970. Control of Road Snow and Ice by Salt and Electrical Road Heating. Highway Research Board's Special Report No. 115.

387. Wester, H.V. and E.E. Cohen. 1968. Salt Damage to Vegetation in the Washington, D.C. Area During the 1966-67 Winter. Plant Disease Report, 52, 5, 5.

388. Westing, A.H. 1966. Sugar Maple Decline: An Evaluation. Botany 20.

389. White, B.G. 1957. Literature Survey of Use of Heat for Keeping Roads, Sidewalks, etc. Clear of Snow and Ice. 1957. Canada National Research Council, Ottawa. NCR-B.S.

390. The White House. 1965. Restoring the Quality of our Environment. Report, Washington, D.C.

391. Whittle, C.L. 1971. The Case Against the Use of Highway De-icing Salts for Snow and Ice Control in Newston. Newtonville, Mass.

392. Wiebe, H.H. and J.H. Walter. 1972. Mineral Iron Compositon of Halophytic Species from Northern Utah. The American Midland Naturalist, 87.

393. Williams, J.E. 1949. Chemical Weathering at Low Temperatures. Geographical Rev., 39, 1, 129-135.

394. Williams, J.H. 1970. Absorption and Desorption of Inorganic Phosphorus by Lake Sediment in a O.I.M. NcCl. Environmental Sci. and Tech., 004.

395. Williamson, P.J. and L.E. Hogbin. 1970. Electrical Load Heating. Road Research Laboratory's Report No. 303, England.

396. Winterrowd, W.H. 1920. The Development of Snow Fighting Equipment. Railway Maintn. Eng., 16, 458.

397. Winters, F. 1970. Pavement Heating. Highway Research Board's Special. Report No. 115.

398. Wood, F.O. 1970. The Role of De-icing Salts in the Total Environment of the Automobile. NACE Symposium.

399. Wood, F.O. 1971. Salt - The Universal De-icing Agent. Syracuse.

400. Woodcock, A.H. 1971. Salt Particles and Raindrops in Hawaii. *Jour. Atmos. Sci.* 28, 7.
401. Work, R.A., et al. 1965. Accuracy of Field Snow Surveys. U.S. Army Cold Regions Research Report No. 163.
402. Wuhrmann, K., and H. Woker. 1953. Influence of Temperature and Oxygen Tension on the Toxicity of Poisons to Fish. *Proceedings Inter. Assoc. Theor. and Applied Limn.*, 12.
403. Xanten, W. A. 1962. Fixed Emergency Snow Measures. *The American City*, 77.
404. Zelazny, L.W. 1968. Salt Tolerance of Roadside Vegetation *Proceedings of the Symposium: Pollutants in the Roadside Environment.* University of Connecticut Report.
405. Zulauf, R. 1966. Injury to Plant Life by Anti-freeze Salts in Winter. *International Road Federation Report*, Switzerland.

LIST OF SOURCES OF REVIEWED LITERATURE AND
ENVIRONMENTAL AUTHORITIES CONSULTED

1. Department of Public Works, (Mr. A.W. Pellegrino),
City of Toronto.
2. Environment Canada - (Mr. M. Schultz)
Ottawa, Ontario.
3. Highway Research Information Services,
Washington, D.C., U.S.A.
4. Information Salt,
Montreal, P.Q., Canada.
5. Madison Rivers and Lakes Commission,
Madison, Wisconsin.
6. McMaster University, (Dr. J. Kramer),
Hamilton, Canada.
7. Minnesota Pollution Control Agency,
(Mr. R.D. Anderson),
Minneapolis, Minnesota, U.S.A.
8. Michigan Department of Highways,
(Mr. G.R. Adams),
Lansing, Michigan. U.S.A.
9. Michigan Department of Natural Resources,
(Mr. W.G. Turney),
Lansing, Michigan. U.S.A.
10. New York State Department of Environmental Conservation,
Albany, N.Y., U.S.A.
11. National Referral Centre,
Library of Congress,
Washington, D.C. U.S.A.
12. Ontario Ministry of the Environment,
(Main Library),
Toronto, Ontario.

13. Ontario Ministry of the Environment,
(Dr. S.N. Linzon), Toronto, Ontario.
14. Ontario Ministry of the Environment,
(A.A. Sobanski), Toronto, Ontario.
15. Ontario Ministry of Transportation & Communications,
(Library), Toronto, Ontario.
16. Ontario Ministry of Transportation & Communications,
(Mr. C.M. Sinclair), Toronto, Ontario.
17. J.L. Richards and Associates Limited,
(Mr. J. Desmaris), Ottawa, Ontario.
18. Salt Institute,
Alexandria, Va. U.S.A.
19. State of Ohio Environmental Protection Agency,
(Mr. J.F. Shea), Columbus, Ohio. U.S.A.
20. University of Toronto,
(Dr. Van Loon), Toronto, Ontario.
21. U.S. Department of the Interior,
(Mr. G.A. Billingsley),
Washington, D.C. U.S.A.
22. U.S. Environmental Protection Agency,
(Dr. D.A. Wallgren),
Chicago, Illinois, U.S.A.
23. Vermont Department of Natural Resources,
(Mr. W. Albert),
Montpelier, Vermont. U.S.A.



(16052)
MOE/REV/ABPV

MOE/REV/ABPV
Ontario Ministry of the En
A review of
literature on the apbv
c.1 a aa